Scientific Journal of Riga Technical University
Material Science and Applied Chemistry

2010

Volume 21

Wear Resistance of Industrial Polymers Under Lubrication with Oils

Audrius Zunda, *Lithuanian university of Agriculture*, Juozas Padgurskas, *Lithuanian university of Agriculture*, Vytenis Jankauskas, *Lithuanian university of Agriculture*, Raimondas Levinskas, *Lithuanian university of Agriculture*, Rimantas Kreivaitis, *Lithuanian Energy Institute*

Abstract: **Wear intensity of sliding friction couples containing different polymers (PA, POM-H and PTFE) is investigated. The friction couples have been tested when lubricated with rapeseed oil, mineral oil SAE 10 and without any lubrication. Research has shown that the lubricating materials are actively absorbed by PA and POM-H polymers (0.6...0.9 mg/cm^2). Lubricating with SAE 10 oil the coefficient of friction of tested polymers is 0.08…0.10, while lubricating with rapeseed oil it is 0.03(PA), 0.10 (POM-H).**

Lubricating with rapeseed oil PETF wear intensity is the lowest and slightly influenced by the load, whereas PA and POM-H wear intensity is directly influenced by the load – the greater the load, the more intensive the wear. Wear intensity of POM-H polymer lubricated with rapeseed oil is 3 times more intensive than lubricated with mineral oil. For this reason the combination of rapeseed oil and POM-H polymer in friction couples is inapplicable. PA is recommended for rapeseed oil lubricated friction couples because of its low wear (0.01…0.03 µm/m) and low coefficient of friction (0.03).

Keywords: **Industrial polymers, sliding friction couples, wear intensity, lubrication, load**

I INTRODUCTION

Industrial polymers are widely used as non metal engineering materials exhibiting good fatigue and creep resistance, high impact strength, low friction coefficient and good wear-resistance properties. Polymers, such as poliamide (PA) and homogenious polyoxymethylene (POM-H), are used for making bearings, gears, chain leads, vibration or noise dampers [1, 2] and other friction couples. In some cases polymeric materials can replace nonferrous metals, such as Cu, Zn and Cr, in specific cases - iron castings, steel castings and stainless steel [3]. Many polymeric materials have gained popularity due to excellent characteristics, such as low cost, good lubricity, low weight, and high corrosion resistance. Among polymeric materials, for example, polyethilenteraftalate (PETF), considered as remarkable solid lubricant exhibiting the lowest coefficients of static and dynamic friction, has been widely used as a self-lubricant [4].

Polymers used in tribosystems are working under various conditions, i.e. usually without any lubrication or sometimes lubricated with grease or oil. There is some difference in the action between the surfaces of a friction couple under lubrication compared to that under dry conditions.

Dry sliding of polymer – polymer combinations always produce an intermittent motion and seizure or stick – slip due to adhesion, while the adhesion might be considerably influenced or changed in different ways. The rough-on-rough surface sliding combinations have higher friction coefficients than those of smooth-on-smooth surface combinations. Due to frictional hardening or orientation and adding solid lubricants to a polymer matrix can decrease adhesion of two sliding surfaces. Polymers have a low friction coefficient due to flexibility of linear molecular chains. It is generally known that external lubrication is a useful method of reducing adhesion of two sliding surfaces [5, 6]. The type of oil can play an important role in the wearing rate of polymer. Several researches have proved that the behavior of polymers in mineral oil differs from that in synthetic lubricant [7]. The wear mechanism of polymers can be analyzed not only using traditional factors, such as friction torque, friction coefficient, wear rate, but a wear product as well [8] or the state of wear surface [9], especially in dry wear or wear in abrasive.

II EXPERIMENTAL

A Materials and equipment

PA, PETF, POM-H were used in this study as subjects of research. Samples were taken from commercial sticks and turned into pins of 10 mm in diameter and 28.5 mm length. To reduce the load on a tribometer (Fig. 1 a) construction, a special zone was made on a polymer stick (Fig. 1 c) 6 mm in diameter and 2.5 mm height (Fig. 1 c). Three samples were made of each polymer for every condition. Counter samples (discs) were made of carbon steel C45 (EN 10250-2:1999) tempered to 30 HRC and polished to R_a = 0.7...0.9 µm. Thermal and mechanical properties of polymers are listed in Table 1.

B Wear test

Wear tests were conducted under dry conditions and lubricating with mineral oil SAE 10 and rapeseed oil (RO). Tribometer TRM 500 (Dr. Wazau GmbH, Germany) was used for determining all tests data (Fig. 1 a). Normal load force, friction torque, coefficient of friction and oil temperature were collected to personnel computer (PC). During dry wear test the Fluke Ti20 termovisor was used for measuring the sample temperature. When lubricating friction couples the temperature of samples was determined according to that of the lubricated material.

Initial oil temperature was 20...22 °C. The wear test regimes for all conditions were: 1) dry, 2) in SAE 10 oil, 3) in rapeseed oil. Accordingly the load was 3, 6 and 9 MPa; sliding velocity – 0.33 m/s and sliding distance - 600 m.

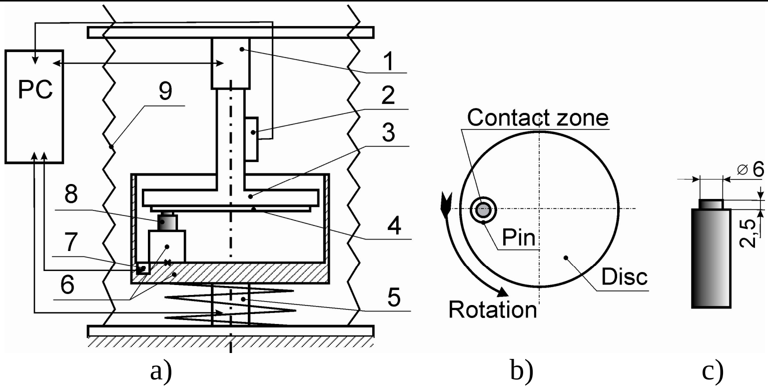


Fig. 1. Principal scheme of tribometer TRM 500: a) 1 - rotator drive, 2 - torque sensor, 3 - counter sample holder, 4 - counter sample (disc), 5 - load sensor, 6 - oil pot with a sample holder, 7 - temperature sensor, 8 - sample (pin), 9 - load drive; b) scheme of a friction couple; c) sample (pin)

TABLE 1
PROPERTIES OF USED POLYMERS [10]

Properties \ Polymer	Standard	PA	PETF	POM-H
Hardness, N/mm^2 HRM	ISO 2039-2	85	94	88
Thermal expansion coefficient, m/(m·K)·10^{-6} at (23/100 °C)	ASTM D696-08	90/105	65/85	95/110
Compressive modulus of elasticity (δ 1% strain), N/mm^2	ISO 604	82	99	70
Friction coefficient	PTM55007 (USA)	0,4-0,6	0,2-0,3	0,15-0,2
Melting point, °C	ASTM D3418	220	255	175
Working temperature, °C		70-85	100-115	90-105

All these regimes were chosen for estimating the behavior of polymers under continually changing conditions. In this paper only the first three stages are taken for analysis.

To find out how polymers absorb different oil, additional tests were performed. The samples of polymers were steeped into oil SAE 10 and RO for 300 hours at 60 °C temperature. The quantity of absorbed SAE 10 and rapeseed oils was evaluated by weighing the samples on scales Sartorius AC210S (accuracy 0.1 mg) before and after testing. Wear intensity was evaluated from displacement of a sample dimension recorded on tribometer TRM 500. To calculate wear intensity the sliding path part (Δl=300 m, Fig. 2 a), in which length of a sample was steadily varying, was taken from the displacement graph.

III RESULTS AND DISCUSSION

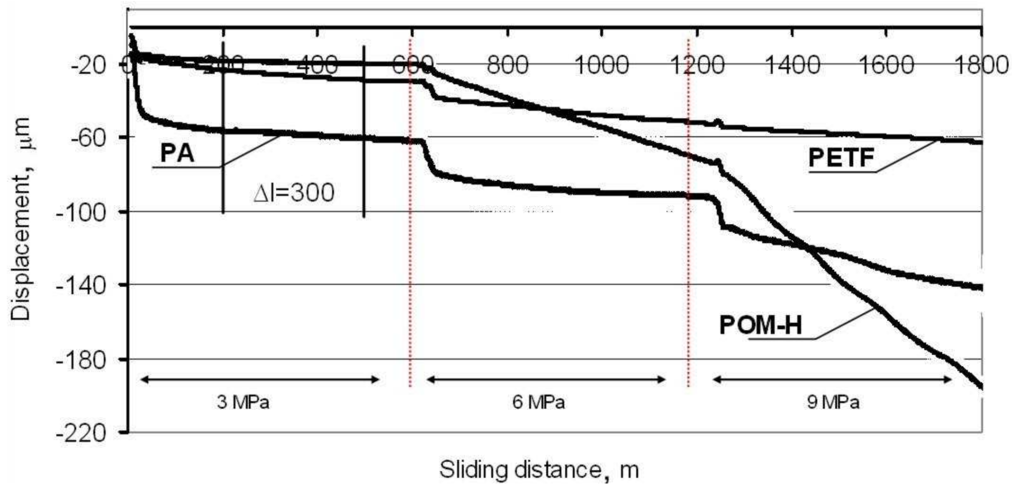
Under low comparative loads of sliding friction couples "steel - polymer", either no lubrication or self-lubricating polymers are used. With an increase in sliding speeds and loads lubrication becomes a requisite to reduction in friction, heating, thus to the wear. Lubricating materials, especially those affecting the polymer structure, may significantly influence the wear.

A molecular structure of polymeric materials determines their ability to absorb liquids. In this approach they are unequally sensitive to various solvents – mineral oils and biological oils [5]. The experiments on absorption of mineral oil SAE 10 and RO have shown that polymers PA and POM-H absorb 0.6 mg/cm^2 of rapeseed oil and only 0.08 mg/cm^2 for PETF. These materials differently absorb mineral oil – PA - 0.9 mg/cm^2, POM-H - 0.6 mg/cm^2, PETF - 0.3 mg/cm^2.

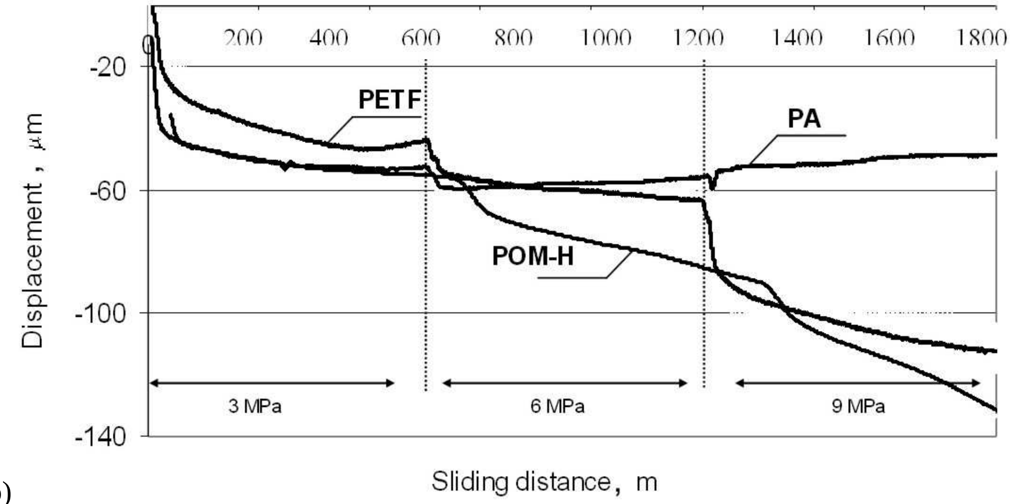
The initial data of polymers wear tests lubricating them with oil SAE 10 and RO or not lubricated are presented in Fig. 2 a-b. The laser wear recording system of tribometer TRM 500 recorded the influence of time (sliding path) on the samples length. These data have allowed determining the wear of samples, the total of mechanical (increasing the load) and temperature deformations.

Testing non-lubricated friction couples the temperature of polymer samples has reached 90 ^{o}C. This temperature for polymer PA is higher than the operating one (Table 1). Testing lubricated friction couples the oil temperature was lower than 30 ^{o}C.

The polymer deformations are noticed at the moments of load addition (up to 3 MPa) and increase (from 3 to 6, from 6 to 9 MPa). The polymer PA samples become most deformed when with addition of 3 MPa load they shorten up to 50 µm, and with a load increase – 20 µm. Deformations of other polymers POM-H and PETF are smaller - up to 10…20 µm (Fig. 2 a).



a)



b)

Fig. 2. Displacement data of polymers lubricated with rapeseed oil (a), mineral oil SAE 10 (b)

Wear intensity is estimated according to the curve slope under the steady operating regime (wear increases with an increase of negative dimensions values). The graphs of the length variation of polymers PA, PETF and POM-H samples with lubricated friction couples with mineral oil SAE 10 (at 6 and 9 MPa, Fig. 2 b) indicate elongation of samples. When a friction couple does not reach thermodynamic equilibrium over 600 meters of working path – a sample is elongating. It indicates the unsettled state of material under the operating conditions therefore no general conclusions have been drawn. Only that the oils absorption causes microstructural swell of polymer and this influences on creep and stress relaxation processes in polymer matrix.

Wear intensity of polymers lubricated with RO is influenced by the load (Fig. 2 a). Wear intensity of polymer POM at 3 MPa is the lowest, while at 6 and 9 MPa it is higher than that of other polymers. The magnitude of PA load is also directly increasing wear intensity. This material is mostly affected by mechanical deformation when loading. Within the boundaries of all loads polymer PETF is the least sensitive to load, due to its additional self-lubricating (has some fluorine) properties.

Lubricating friction couples with mineral oil SAE the length of polymer PETF is unsteady at 3 MPa load, with a further increase in load the wear is intensifying (Fig. 2 b). A sample of polymer POM-H is intensively shortening at even 6 MPa load, heating has a dominating effect on PA samples length variation (thermodynamic equilibrium is not reached), therefore this case is not analyzed.

Due to the dominating effect of heating on the samples length when they are tested at dry friction (without lubrication) only the coefficients of friction are determined. The coefficients of friction of a friction couple under lubricating and non-lubricating conditions are given in Fig. 3. A coefficient of friction of lubricated polymers is about 50 % lower. Rapeseed oil reduces it by 2.2 times (up to 0.03) in friction couples containing polymer PA.

To analyze polymers resistance to wear the wear intensity diagrams are drawn after Figure 2 data (under thermodynamic equilibrium) (Fig. 4).

Analyzing the wear data when lubricating with RO, the regularities have been studied - PETF wear is slight and rather equal in the range of all loads (Fig. 4). The wear of PA and POM-H polymers is directly proportional to the load. POM-H wears mostly when lubricated with rapeseed oil, which might be due to an oil effect on the friction surface, though the absorption of lubricating materials has shown that polymers PA and POM-H were absorbing equal RO quantities.

The friction pairs containing PA lubricated with rapeseed oil are not recommended to load by 9 MPa and POM-H by 6 MPa load because of their increased wear intensity.

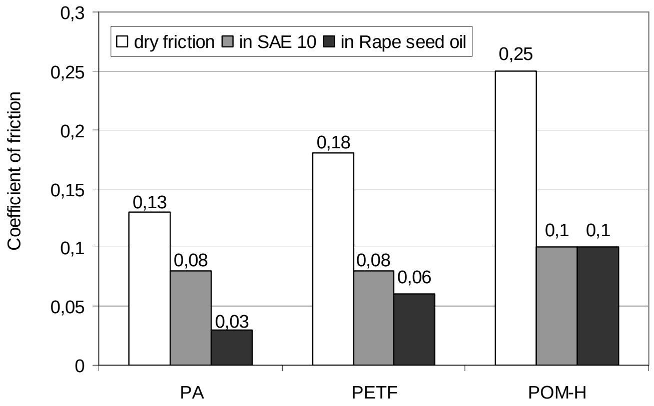


Fig 3. Coefficient of friction measured during wear test

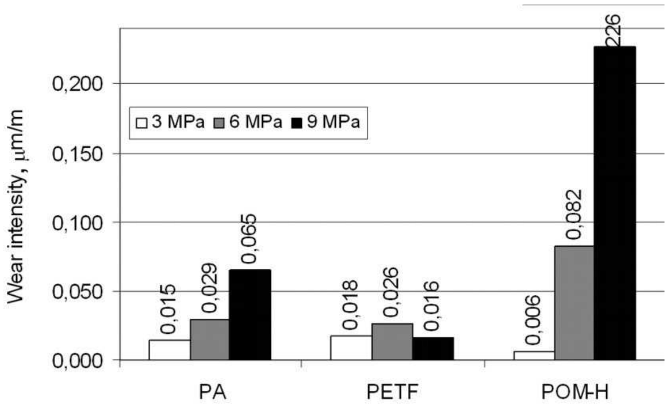


Fig 4. Wear intensity of polymers lubricated with rapeseed oil (RO)

The load of friction couple lubricated with oil SAE 10 directly influences the wear as well. Lubricating with oil SAE 10 (at 9 MPa) polymer POM-H is wearing most intensively, however its wear is 2 times higher than polymer PETF. Comparing wear test results of polymers in RO and oil SAE 10 the wear intensity in oil SAE 10 is 2-3 times lower than in RO especially at 9 MPa load. Wear intensity of polymer samples depends on the load, and at 9 MPa load the wear is twice more intensive.

In a dry friction case the method of polymers wear intensity measurement based on continuous linear wear recording must not be applied. The reason lies in the samples temperature which affects their length, changes their mechanical properties thus conditioning deformation of working surfaces (displacement deforms the end of a sample in the friction couple motion direction). In a dry friction case estimation of wear by the length of micro-meters or mass change is more advantageous than the immediate length recording during the samples wearing process.

IV CONCLUSIONS

1. Most of rapeseed oil is absorbed by PA and POM-H (0.6 mg/cm^2), least – by PETF (0.08). Absorption of mineral oil differs: PA (0.9), POM-H(0.6), PETF (0.3 mg/cm^2).
2. Under both lubrication and dry friction operating conditions PETF demonstrates best wear resistance properties (under the load of 9 MPa its wear intensity is low and varies slightly).
3. When lubricated with rapeseed oil PETF wear intensity is the lowest and slightly influenced by the load, whereas wear intensity of PA and POM-H polymers depends directly on the load level. Wear intensity of POM-H polymer lubricated with rapeseed oil is 3 times higher than that lubricated with mineral oil, therefore the friction couples containing the combination of these materials are short-lived.
4. When lubricating with mineral oil SAE 10 the coefficient of friction is practically the same in all tested polymers (0.08…0.10), lubricating with rapeseed oil the difference is observed: 0.03 (PA), 0.10 (POM-H). To reduce friction and wear the friction couples containing polymer PA loaded up to 3 MPA should be lubricated with rapeseed oil.
5. The wear intensity estimation methods applying the tribometers continuous linear wear recording system data for polymers and other temperature sensitive materials as well as for non- lubrication tests should not be used.

REFERENCES

1. **Dasari A., Yu Z-Z., Mai Y-W., Hu G-H., Varlet J.** Clay exfoliation and organic modification on wear of nylon 6 nanocomposites processed by different routes // Composites Science and Technology 65 (2005), 15-16, P.2314-2328.
2. **Nozawa J.-I., Komoto T., Kawai T., Kumehara H**. Tribological properties of polymer-sheet-adhered metal hybrid gear // Wear 266 (2009), P.893–897.
3. **Li, W.Z. Zhang,** Application research of modified POM three layers composite, J.Beijing Univ. Chem. Technol. 27 (2) 39–41. (2000)
4. **Khoddamzadeha A., Liua R., Wu X.** Novel polytetrafluoroethylene (PTFE) composites with newly developed Tribaloy alloy additive for sliding bearings // Wear 266 (2009), P.646–657.
5. **Jia B.-B., Li T.-Sh., Liu X.-J., Cong P.-H.** Tribological behaviors of several polymer–polymer sliding combinations under dry friction and oil-lubricated conditions. Wear 262 (2007), P.1353–1359.
6. **Suna L.-H., Yang Z.-G., Li X.-H.** Study on the friction and wear behavior of POM/Al_2O_3 nanocomposites // Wear 264 (2008), P.693–700.
7. **Fernįndez Ricoa E., Minondob I., Garcķa Cuervo D.** Rolling contact fatigue life of AISI 52100 steel balls with mineral and synthetic polyester lubricants with PTFE nanoparticle powder as an additive. Wear 266 (2009), P.671–677.
8. **Kowandy C., Richard C., Chen Y.M.** Characterization of wear particles for comprehension of wear mechanisms: Case of PTFE against cast iron // Wear 265 (2008), 11-12, P.1714-1719.
9. **Žunda A., Stakvilevicius D., Jankauskas V., Padgurskas J.** The investigation of abrasive wear resistence of plastic // Balttrib'2005: international conference materials: 17-18.11.2005, Kaunas, Lithuania. Akademija, 2005. P.70-71.
10. About Quadrant. http://www.quadrantepp.com (01.07.2009).

Juozas Padgurskas, Professor, Professor,
Lithuanian university of Agriculture, Studentu g. 15-216, LT-53361, Akademija, Kauno r.,
Phone: +370 37 752263,
e-mail: juozas.padgurskas@lzuu.lt

Vytenis Jankauskas, Docent, Professor,
Lithuanian university of Agriculture, Studentu g. 15-216, LT-53361, Akademija, Kauno r.,
Phone: +370 37 752263,
e-mail: vytenis.jankauskas@lzuu.lt

Audrius Žunda, Docent, Doctor,
Lithuanian university of Agriculture, Studentu g. 15-216, LT-53361, Akademija, Kauno r.,
Phone: +370 37 752263,
e-mail: audrius.zunda@lzuu.lt

Raimondas Kreivaitis, Postgraduate, Master,
Lithuanian university of Agriculture, Studentu g. 15-216, LT-53361, Akademija, Kauno r.,
Phone: +370 37 752263,
e-mail: raimondas.kreivaitis@lzuu.lt

Rimantas Levinskas Deputi director, Doctor,
Lithuanian Energy Institute, Breslaujos g. 3,
Phone +370 37 401804, e-mail: Levin@mail.lei.lt

Audrius Žunda, Juozas Padgurskas, Vitenis Jankauskas, Raimondas Kreivaitis, Rimantas Levinskas. Industriālo polimēru nodilumizturība pēc lubricēšanas ar eļļām.
Darbā izpētīta dažādus polimērus (PA, POM-H un PETF) un metālu saturošu slīdošu berzes pāru berzes koeficienti un nodiluma intensitāte. Berzes pārus testēja bez lubricēšanas un pēc lubricēšanas ar rapšu eļļu un minerāleļļu SAE 10. Pētījumi parādīja, ka PA un POM-H aktīvi absorbē (0.6...0.9 mg/cm^2) lubricējošos materiālus, bet PETF ievērojami mazāk un , slogojot pat līdz 9 MPa, tas nodilst vismazāk gan bez eļļotāja, gan ar to. SAE gadījumā nodiluma intensitāti praktiski neietekmē pieliktās slodzes lielums. Lubricējot ar SAE 10 eļļu, visu testēto polimēru gadījumos berzes koeficients mainās maz un ir robežās no 0.08 līdz 0.10, kamēr lubricējot ar rapšu eļļu, tie ir trīs reizes mazāki 0,03 (PA) un 0.10 (POM-H).
Lubricējot ar rapšu eļļu, PETF nodiluma intensitāte arī ir viszemākā un to nedaudz ietekmē pieliktās slodzes lielums, kamēr PA un POM-H nodiluma intensitāti tieši ietekmē pieliktā slodze – jo lielāka tā ir, jo intensīvāks ir nodilums. Ar rapšu eļļu lubricēta POM-H nodiluma intensitāte ir trīs reizes intensīvāka nekā ar minerālo eļļu lubricēta. Līdz ar to metāls, rapšu eļļas un POM-H kombinācijas izmantošana šim berzes pārim nav piemērota. Savukārt metāls-PA berzes pāru eļļošanai ir rekomendējama rapšu eļļa, jo tā rada mazu nodilumu (0.01…0.03 μm/m) un tai ir zems berzes koeficients (0.03). Polimēru un citu temperatūras jūtīgu materiālu gadījumos nerekomendē izmantot nepārtrauktas tribometrijas pārbaudes metodes, bet it īpaši eksperimentos, kuros netiek lietots eļļotājs

Аудриус Жунда, Юозас Падгурскас, Витенис Янкаускас, Раймондас Крейвайтис, Римантас Левинскас. Износостойкость промышленных полимеров смазывая маслами.
В данной работе приведены результаты исследований коэфицентов трения и интенсивности изнашивания пар трения сталь – пластик с тремя разными пластиками (ПА, ПОМ-Н и ПЭТФ). Исследованные пары трения смазывали минеральным (SAE 10) и рапсовым маслами, а также испытания проводили в режиме сухого трения. Испытания абсорбции смазочных материалов показали, что пластики ПА и ПОМ-Н абсорбируют смазку 0,6…0,9 мг/см^2, ПЭТФ – значительно меньше – 0,08…0,3 мг/см^2. При этом у ПЭТФ интенсивность изнашивания самая низкая и практически не зависит от приложенной (до 9 МПа) нагрузки. При смазке маслом SAE 10 коэффициент трения меняется мало и составляет 0,08…0,1, при смазке рапсовым маслом он в три раза меньше– 0,03 (PA), и 0,1 (ПОМ-Н).
При смазке рапсовым маслом наименьшее изнашивание и влияние нагрузки на интенсивность износа имеет пластик ПЭТФ. Износ пластиков ПА и ПОМ-Н зависит от уровня нагрузки (чем нагрузка больше, тем изнашивание интенсивнее). Пластик ПОМ-Н в среде рапсового масла изнашивается в 3 раза интенсивнее, чем смазываемые минеральным маслом. Поэтому сочетание рапсового масла и пластика ПОМ-Н в парах трения с металлами является неприемлемым. Пластик ПА с рапсовым маслом смазываемых парах трения с металлами (нагрузка до 6 МПа) выгоден с точки зрения малого износа (0,01…0,03 мкм/м) и малого коэффициента трения (0,03). Полимеры и другие термочувствительные материалы не следует проверять непрерывными трибологическими методами, особенно в тех случаях, когда не используются смазывающие вещества.

.